1. Introduction

Deep drawable cold rolled sheets are important steel products which are widely applied in such industry as automobile. Good drawing properties are basic requirements for deep drawable cold rolled sheets. Such sheets are usually produced with conventional hot bands and usually have good drawing properties that well satisfy the requirements of automobile industry. Now more and more thin slab casting and rolling (TSCR) production lines have been used in the production of hot strips. Accordingly more hot bands rolled with TSCR have been used to produce drawable cold sheets. In the production, however, it was found that the drawing properties of cold sheets rolled with TSCR hot bands were caused by the differences in chemical composition, microstructure, cementite distribution and inclusion type. The suggestions are given to improve the drawing properties of TSCR hot-bands based cold sheets.

2. Properties of Cold Sheets

Cold sheets from four cold mills have been used to produce the automobile body and it is found that these cold sheets have different drawing quality in practice. In order to investigate the reasons of different drawing quality, samples of two kinds of cold sheets were taken in an automobile plant, in which samples A, B, C are cold sheets rolled with conventional hot bands (also termed as conventional cold sheets) and samples D is cold sheet produced with TSCR hot bands (termed as short flow cold sheets). Drawing properties of these samples were measured on Zwick/Roell Z050/SN3A materials tensile machine and are shown in Table 1.

It can be observed that the yield strength of cold sheets from plant A, B and C is lower than that of cold sheets from plant D, while the elongation, plastic strain coefficient $\gamma$ and stain hardening index $n$ of products in plants A, B, and C are higher than that of cold sheets in plant D. The property results correspond to the application results of cold sheets in the automobile plant.

3. Chemical Composition

Chemical compositions of cold strips from four cold mills were analyzed by IRIS advantage inductively coupled plasma atomic emission spectrophotometer and the results are shown in Table 1.

Table 1. Drawing properties of cold sheets from different plants.

<table>
<thead>
<tr>
<th>No.</th>
<th>Samples</th>
<th>$\sigma_{0.2}$, MPa</th>
<th>$\sigma_{m}$, MPa</th>
<th>$\alpha_{90}$, %</th>
<th>$\gamma$</th>
<th>$n$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Plant A</td>
<td>146.07</td>
<td>295.83</td>
<td>49.72</td>
<td>2.08</td>
<td>0.24</td>
</tr>
<tr>
<td>2</td>
<td>Plant B</td>
<td>167.21</td>
<td>302.20</td>
<td>40.53</td>
<td>2.06</td>
<td>0.22</td>
</tr>
<tr>
<td>3</td>
<td>Plant C</td>
<td>160.00</td>
<td>289.93</td>
<td>44.88</td>
<td>2.62</td>
<td>0.23</td>
</tr>
<tr>
<td>4</td>
<td>Plant D</td>
<td>182.81</td>
<td>318.65</td>
<td>36.26</td>
<td>1.83</td>
<td>0.28</td>
</tr>
</tbody>
</table>
Table 2. Chemical compositions of cold sheets from different plants.

<table>
<thead>
<tr>
<th>Samples</th>
<th>C</th>
<th>O</th>
<th>N</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Al</th>
<th>Ti</th>
<th>Nb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant A</td>
<td>0.0052</td>
<td>0.00410</td>
<td>0.00270</td>
<td>0.004</td>
<td>0.14</td>
<td>0.013</td>
<td>0.007</td>
<td>0.030</td>
<td>0.045</td>
<td>0.001</td>
</tr>
<tr>
<td>Plant B</td>
<td>0.0057</td>
<td>0.00419</td>
<td>0.00260</td>
<td>0.006</td>
<td>0.15</td>
<td>0.011</td>
<td>0.006</td>
<td>0.043</td>
<td>0.032</td>
<td>0.003</td>
</tr>
<tr>
<td>Plant C</td>
<td>0.0039</td>
<td>0.00365</td>
<td>0.00249</td>
<td>0.005</td>
<td>0.15</td>
<td>0.008</td>
<td>0.005</td>
<td>0.033</td>
<td>0.050</td>
<td>0.001</td>
</tr>
<tr>
<td>Plant D</td>
<td>0.0081</td>
<td>0.00453</td>
<td>0.00314</td>
<td>0.029</td>
<td>0.23</td>
<td>0.016</td>
<td>0.005</td>
<td>0.036</td>
<td>0.005</td>
<td>0.001</td>
</tr>
</tbody>
</table>

It has shown that the element contents of C, Si, Mn and P of sample from plant D are obviously higher than those of samples from other three plants. Other element contents are similar for samples of four plants. Generally, the higher the contents of C and Mn, the greater the yield strength of cold sheets. The greater yield strength is harmful to drawing properties of sheets. Therefore, higher C and Mn content is one of the reasons of worse drawing properties in plant D.

4. Microstructure Analysis

Microstructures of the four different cold sheets were observed by Zeiss Axioplan 2 imaging optical microscope, and the results are shown in Table 3.

It is given that the grain sizes of samples from plant A, C, and D are the same except the sample of plant B with 7 to 8 grain grade. In addition, inclusion classes for all samples have the same value. However, the cementite class of specimen D is different from those of specimens A, B and C. The SEM micrographs showing cementite carbide distribution of samples C and D are given in Fig. 1. Cementite class A2 of sample D indicates that the iron carbides distribute along the grain boundaries (Fig. 1(b)) and iron carbide particle is larger, which is harmful to the drawing properties of cold sheets. Cementite class B0.5 of sample C means that the iron carbides distribute in the grains (Fig. 1(a)) and iron carbide particle is smaller, which is beneficial to the drawing properties of cold sheets. Therefore, the cementite class is one of the reasons that lead to the worse drawing properties of sample D. This is in coincidence with the customers’ comments on quality of different cold sheets.

5. Inclusion Investigation

To analyze the differences of inclusion type, inclusion distributions were scanned with a FEI NOVA 400 NANO scanning electronic microscope (SEM) at Wuhan University of Science and Technology and inclusion types were determined with a PHOENIX EDAX energy spectrometer. Figure 2 is one of the SEM micrographs and energy spectra of inclusion of sample B, while one of the SEM micrographs and energy spectra of inclusion of sample D is shown in Fig. 3. Table 4 and Table 5 respectively give the element contents of inclusions in weight percentage and atom percentage corresponding to Fig. 2 and Fig. 3.

According to the SEM micrographs and energy spectrum...
results, inclusions of sample A, B and C are similar and include Al₂O₃, MnS and TiN particles etc., while both Al₂O₃, MnS and CaO·Al₂O₃ were contained in sample D. CaO·Al₂O₃ inclusion in specimen D indicates that cold sheets of plant D have more impurity than cold strips of other three plants. This is another reason of worse drawing properties of cold sheets in plant D.

6. Discussions

As mentioned above, many differences exist in chemical compositions, microstructure, cementite distribution and inclusion type between cold sheets of plant D and cold strips of plants A, B and C. These differences cause the drawing properties of cold strips of plant D to be worse. The higher impurity content and more inclusions in sample D result from the chemical compositions of sample D. It can be noted from Table 2 that contents of C and Si of sample D are obvious higher than those of samples A, B and C. In addition, sample D contains more Mn, N and P elements than other three samples. It is all known that more Mn, N and P elements in steel will result in more inclusions in final products.

The cementite distributed along grain boundaries in sample D results from more carbon content, improper hot rolling and annealing technology. When the finishing rolling and coiling temperatures are higher during hot rolling, carbon atoms, which are interstitial atoms, will diffuse more easily from ferrite grains to grain boundaries to reduce free energy in microstructure and thus to form cementite along grain boundaries, which will inherit from hot bands to cold sheets. Furthermore, higher annealing temperature and longer annealing time will also cause carbon atoms to diffuse to grain boundaries and form the cementite distributed along grain boundaries, which will lead to the deterioration of drawing properties of cold rolled sheets.

Therefore, in order to improve the drawing properties of cold sheets in plant D, chemical compositions should be optimized by using RH vacuum refining equipment, and cementite distribution should be changed by reducing finishing and coiling temperatures in hot rolling. At the same time, CaO·Al₂O₃ inclusion should be reduced as much as possible during steel refining.

7. Conclusions

The difference of drawing properties results from the differences in chemical components, microstructure, cementite distribution and inclusion type. To improve the drawing properties of cold sheets based on TSCR hot bands, following precautions should be taken in the production of cold sheets:

(1) Chemical compositions should be optimized; especially, C, Mn and Si contents should be as low as possible;
(2) Production technology, including finishing and coiling temperatures, annealing temperature and annealing time, should be modified to make the cementite distribute in grains;
(3) CaO·Al₂O₃ inclusion should be reduced as much as possible.

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REFERENCES